The Interaction of the Throughflow with Smaller Scale Variability

Janet Sprintall
Scripps Institution of Oceanography, UCSD
9500 Gilman Drive
La Jolla CA 92093-0230
phone: (858) 822-0589 fax: (858) 534-9820 email: jsprintall@ucsd.edu

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LONG-TERM GOALS

The long-term goal is to understand the processes that control the generation, evolution and distribution of small-scale, time-dependent features within straits, and how these features interact with the large-scale sub-tidal throughflow within which they are embedded. The effort will focus on a multi-year time series from an ocean sensor array of moored ADCP and temperature-conductivity sensors, and pressure gauge observations in the internal straits of the Philippine archipelago. The aim is to characterize the spatial and temporal variability of the small-scale features and large-scale flows, and how they may vary seasonally to interannually as the remote and local (monsoonal) forcing changes. Ultimately, this will enable a better representation and prediction in numerical and theoretical models of the structure and evolution of the small-scale features common to sea straits, including their time-dependent variability.

OBJECTIVES

The primary objective is to improve our understanding of the oceanographic processes that lead to small-scale variability in the flow structure of straits. Specifically, the main objectives are:-

1. To examine the relative roles of the tidal and longer timescale flows in the generation and evolution of the small-scale dynamical flow features in straits,

2. To determine how small-scale features evolve with across- and along-strait variation in sea-level and the corresponding strength and direction of the mean flow,

3. To identify how the small-scale flow structures and sea-level variability may be modulated by both the remote and the local forcing, particularly in response to the seasonal reversal in the monsoon winds.

APPROACH

As part of the "Characterization and Modeling of Archipelago Strait Dynamics" DRI, an ocean sensor array of moorings and pressure gauges were deployed within the straits of the Philippine archipelago (Figure 1). The array of moorings and pressure gauges within these straits resolves both the along-strait

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and the cross-strait variation in flow and properties, and enables us to observe any response in the circulation patterns related to the mesoscale and submesoscale processes. The straits connect the internal Philippine seas to the large-scale flow from the Western Pacific and the South China Sea.

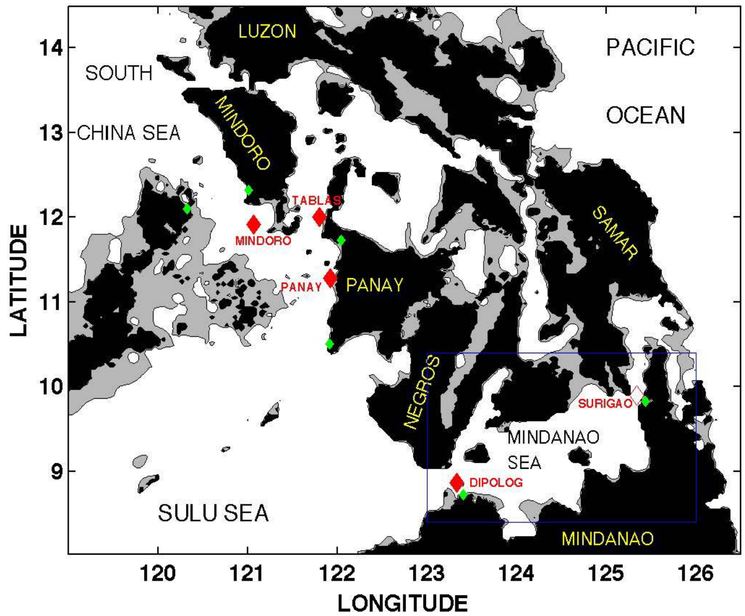

Figure 1: a) Regional map showing the location of PhilEx deployed moorings (red diamonds) and pressure gauges (green diamonds).

The moorings consisted of ADCPs to measure water-column currents, and discrete Temperature-Salinity sensors. The moorings provide direct measurements of the velocity, temperature and salinity at sampling rates of ~ 0.5 hours. The pressure gauge array help resolve the sea level signal associated with the tidal forcing (to assist with the validation of the barotropic tidal models) and the leakage of long planetary waves from the boundaries of the Philippines seas. SBE37 CTDs co-located with the shallow pressure gauges add some information on surface temperature and salinity variability. The Paroscientific quartz pressure sensors return high precision (0.3 mbar) data with sampling periods of 10 seconds to accurately resolve the tidal flow and changes in sea level (pressure) along and across the strait.

The ocean sensor array was constructed and assembled by engineers and marine technicians at the Scripps Institution of Oceanography (SIO) Hydraulics Laboratory, under the guidance of Senior Development Engineer Mr. Paul Harvey.

The shallow pressure gauge array was deployed at 6 locations within the Philippines with the assistance of Dr. Cesar Villanoy and his team at the University of the Philippines.

WORK COMPLETED

Moorings were deployed in Panay Strait (sill depth ~ 580 m), Dipolog Strait (~480 m), and Surigao Strait (~160 m) during the Exploratory Cruise in the Philippines Seas in June-July 2007. The Panay mooring was deployed initially for a three-week period, recovered and velocity data downloaded, and then redeployed at the end of the cruise. The Panay, Dipolog and Surigao moorings were then recovered during the Joint US-Philippines cruise in November-December 2007. During this first deployment period, the Panay and Dipolog ADCP instrumentation successfully returned 100% of data over the 6-month deployment time period. Unfortunately, the internal card recorder on the ADCP deployed in Surigao Strait malfunctioned and only ~3 days of usable data was returned. Subsequent efforts by the manufacturer RDI Teledyne to recover any other data were not successful. During the Joint Cruise, the moorings were redeployed at Panay, Dipolog and Surigao, and new moorings were also deployed at Tablas Strait (sill depth ~565 m) and Mindoro Strait (~450 m). Shortly after deployment in December 2007, the acoustic releases on the redeployed Surigao mooring failed. However most of the instrumentation was recovered by fishermen, and some usable data (~8 weeks) were recovered from the ADCP and microcat sensors.

During this report period, all moorings were recovered during the RIOP09 *R/V Melville* cruise in March 2009. PI Sprintall and Marine Engineer Paul Harvey participated in this cruise. All ADCPs and temperature sensors returned 100% data during the second deployment period, except for the ADCP designed to capture the bottom flows in Tablas Strait. This ADCP had flooded during the deployment period, and efforts by a commercial data recovery service were unable to extract any data from the ADCP data card. All mooring data were quality controlled and adjusted to account for mooring movement.

Six shallow pressure gauges (see Figure 1) were deployed with the help of University of the Philippine colleagues Drs. Cesar Villanoy and Laura David. Deployment sites and available data (absolute pressure, temperature and salinity) periods are San Jose, Mindoro Island (deployed 11 December 2007); Coron, Calamian Island (15 September 2007 – 15 December 2007; redeploy 2 February 2008); Pandan, Panay Island, collocated with HF radar (21 October 2007 – 24 April 2008; redeploy 24 April 2008); Tobias Fornier, Panay Island, collocated with HF radar (12 August 2007 – 3 May 2008; redeploy 3 May 2008); Dapitan, Apo Island, Bohol Sea (6 October 2007 – 1 July 2008; redeploy 1 July 2008); Surigao, Mindanao Island, Pacific boundary (lost; redeploy 1 June 2008). All pressure gauges were recovered in June-July 2009, and data were quality controlled.

RESULTS

The mooring deployments provide the first time series that measure the flow and properties in these Philippine straits. In this section, I will highlight the ADCP and shallow pressure gauge measurements from the Panay Strait to illustrate some of the distinctive characteristics that are common to many of the measurements.

The mooring deployment in Panay Strait shows an exceptionally vigorous benthic layer (Figure 2). The flow in the lower 100 m is consistently directed toward the southeast, the along channel direction, and results in a strong spill-over into the Sulu Sea. Analysis of Froude number variation across the sill shows the flow is hydraulically controlled (Tessler et al., 2009). Similar strong bottom flow is also found at Dipolog and Mindoro Straits.

Beginning in mid-September 2007, the Panay record shows regular monthly strong pulses of along-strait flow toward the Sulu Sea that extend upwards in the water column to 200 m depth and continue through till around March 2008 (Figure 2). These pulses are again found during the 2008-2009 Northeast monsoon, suggesting that they may be related to the regional wind forcing.

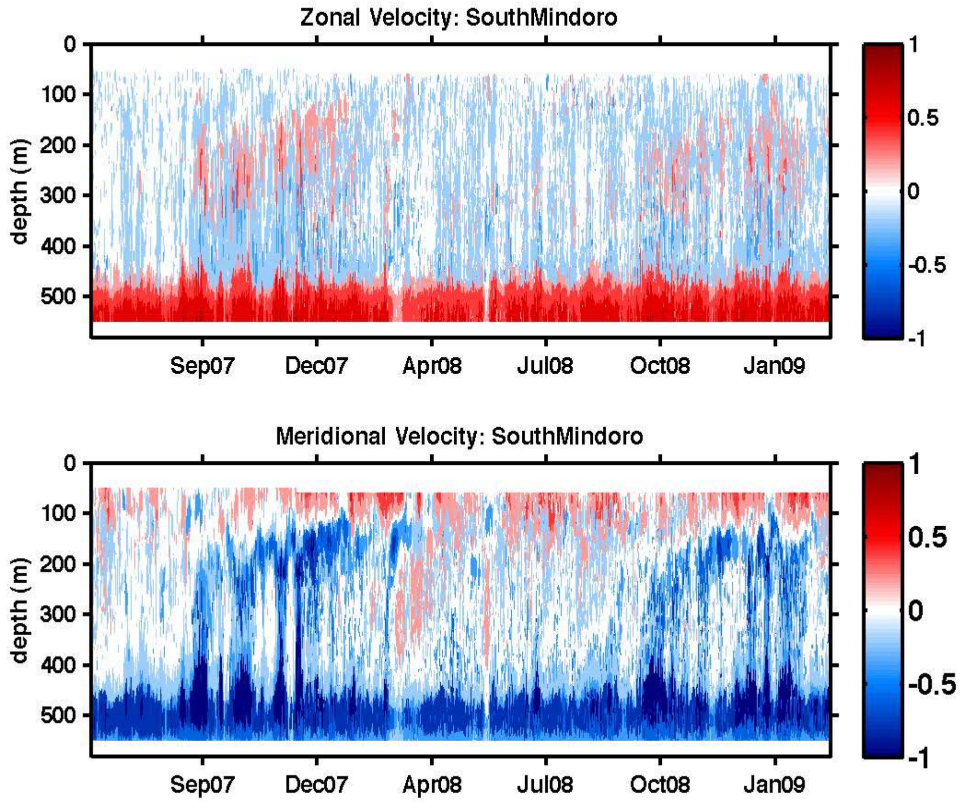

Figure 2: Zonal (top) and meridional (bottom) velocity from the Panay mooring. Note vigorous benthic flows that are hydraulically controlled and act to ventilate the deep Sulu Sea, and the mid-depth southward pulses during the northeast monsoon.

Local and remote winds force equatorial and coastally-trapped waves that can wend their way around the Philippine internal seas. Northward reversals are also evident at mid-depth in March 2008 and again in May 2008. These reversals are also found in the mooring time series in Mindoro Strait, to the north of Panay Strait. We are examining the possibility that they are related to Kelvin waves. These waves are also manifested as pressure (sea level) changes in the coastal waveguides along the islands (Figure 3). Wind and sea surface height data will be used to determine the likely generation region of these waves.

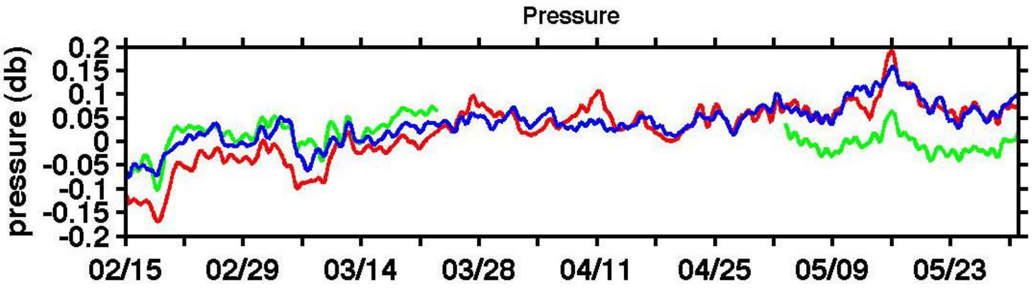

Figure 3: Detided pressure measured at the shallow pressure gauge sites at Dapitan (blue), Tobias Fornier (green) and Pandan (red) show higher pressure signal in March and May 2008 that is probably associated with the passage of Kelvin waves.

The high-resolution mooring records and pressure measurements have also been used to examine the tidal records, and validate tidal models of the region (Logutov, 2008). On tidal time scales, the diurnal lunar and fortnightly tides clearly dominate.

IMPACT/APPLICATIONS

The high-resolution time series data will be used to test the veracity of numerical models in the Philippine region, with obvious application to other archipelago straits characterized by small-scale processes. To date, most of our knowledge of the generation, evolution and fate of these dynamical mesoscale structures within the Philippine seas has come principally from models, which are generally poorly constrained because of the lack of observational data in the region. The high-frequency time series observations will provide a test for evaluation and refinement of all models and their predictions that are not possible from shipborne observations alone. Ultimately, this will enable better representation and prediction of the structure and evolution of the small-scale features, including their time-dependent variability.

RELATED PROJECTS

The ocean sensor array will provide temporal context for the “synoptic” shipborne flow and property measurements taken as part of PhilEx (PI Gordon), as well as ground-truthing of high frequency radar (PI Flament) and SAR images (PIs Asunumu; Jackson; Arnone). The PI is also working closely with numerical modelers (PIs Pullen; Metzger; Hurlbert; Han; Arango) to explore the dynamics of the Philippine seas, as well as using the data to validate the models.

PUBLICATIONS

Logutov, O.G., 2008. A multi-grid methodology for assimilation of measurements into regional tidal models. Ocean Dynamics, 58:441-460. DOI 10.1007/s10236-008-0163-4 [published, refereed]

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